BULLETIN

OF THE

AMERICAN GEOGRAPHICAL SOCIETY

Vol. XLII 1910 No. 7

STUDIES ON CLIMATE AND CROPS*

2. THE YIELD OF WHEAT IN THE UNITED STATES AND IN RUSSIA DURING THE YEARS 1891 TO 1900

BY

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The following figures† show, in millions of bushels, the wheat crops in the United States and Russia for the years 1891 to 1905. The diagram (fig. 1) simplifies the comparison of these figures.

	1891	*1892*	*1893*	*1894*	*1895*	*1896*	*1897*	*1898*	*1899*	*1900*	*1901*	*1902*	*1903*	*1904*	*1905*
U. S.....	611	515	396	460	476	427	530	675	547	522	748	670	637	552	692
Russia..	278	356	478	465	413	412	340	459	454	422	427	607	621	666	636

By this diagram we see at once the extremely interesting fact that during the years 1891 to 1897 and 1901 to 1905 the variation in the values for Russia and the United States is just opposite, while during the years 1897 to 1900, on the contrary, the two curves are similar, the quantity of crops increasing and decreasing simultaneously in the two regions. This fact leads us to the following suppositions:

1. That the variations in harvests are such that very bad years in one region of the globe are precisely years of excellent yield in another region; 2. That the centers of compensation are not always to be observed in the same regions; it does not necessarily follow

* Paper 1 in this series appeared in the April BULLETIN, pp. 270–282.

† I. M. Rubinow: Russian wheat and wheat flour in European markets, p. 15, Washington, 1908 (U. S. Dept. of Agric., Bur. of Statistics.—*Bull.* 66).

that when the crop yield is large in the United States it is small in Russia, or *vice versa;* 3. That to meet the needs of the international market there may be exceptional years of insufficient compensation.

My argument is that these suppositions are well founded. I also admit that a close connection exists between agricultural and climatic variations, and that, in the final analysis, changes in the

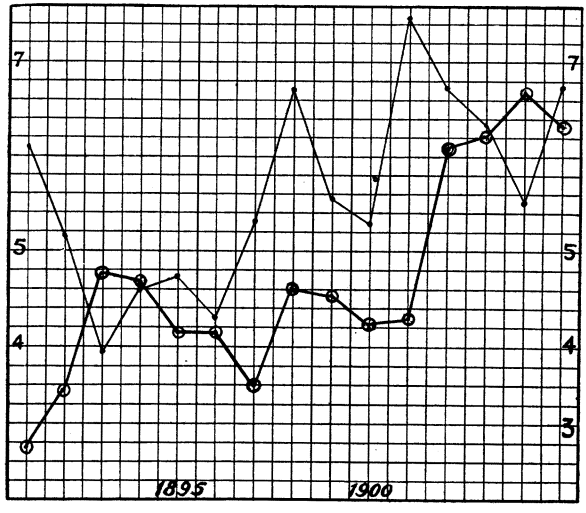


FIG. 1.

quantity of energy radiated by the sun and received by the earth are, most frequently, the cause of temporary increase or decrease in prosperity in different regions of the globe.

Before proceeding further I wish to make two remarks. I must draw attention to the fact that my method of discussing the problem of the influence of the variations of solar phenomena on the yield of crops is quite different from that of W. S. Jevons, Sir John Eliot and others; and then, that the great importance of the influence of climatic variations on crops is far from being recognized by the most competent specialists on the subject.

One of the final conclusions of Professor Cleveland Abbe's report on the relations between climates and crops reads:* ". . . the yield per acre for any one of the ten principal crops . . . has probably never been either increased or diminished by 50 per cent. of

*Cleveland Abbe: First report on the relations between climates and crops, p. 364, Washington, 1905 (U. S. Dept. of Agriculture, Weather Bureau, *Bull.* No. 36).

the normal yield per acre by climatic influences alone over any large region, such as 100 square miles; and, further, the total annual harvest for any given crop in the United States is not likely to be diminished 5 per cent. by the occurrence of an inclement season in some one portion of the country."

At present I could not discuss the question of the climatic influence on the yield of crops in all its details. It is sufficient to look through Professor Abbe's report to see how difficult this question is. But it seems to me that the first work to be done, preparatory to discussing the problem, is purely geographical, because, in order that it may be possible to learn for what regions (and for what years) the meteorological conditions should be especially studied, from month to month, we must know the geographical distribution of excess and deficit in the yield of crops.

Such is precisely the object of this paper.

Now, coming back to the wheat crops in the United States and in Russia, we must observe that, taking into consideration the increase in population and the improvements in agriculture, it is easy to understand why the two curves of my diagram must ascend, and, from that fact, one must admit that the sudden falls of the curves are due to natural causes, independent of the will of men or needs of the market.

Now, in the United States the production of wheat fell off, during the years 1891 to 1893, from 611,780,000 to 395,132,000 bushels, a difference of 215,648,000.

The same is noted from 1898 to 1900, and from 1901 to 1904 the decrease was quite as characteristic.

In Russia the curve descends from 1893 to 1900, and the contrast in the values of the years from 1902 to 1905 with those of the preceding years is very marked. To have comparable figures, and independent of the areas of soil used for agricultural purposes, it is necessary to consider the yield per acre. Notice now, that a decade of years is a period of time not long enough to have the figures much influenced by agricultural improvements, which would increase the yield of crops, and that the soil, in a region of new colonization, cannot be exhausted to any great extent in ten years. In consequence, it seems to me that instead of comparing the yield per acre from one year to the next, and from one region to another, it is just as well to consider the annual departures from the means of a period of ten years.

For example: the yield per acre in the State of Maine in 1891 was 16.3 bushels, in 1892, 16.7, &c., and the mean for the years

1891 to 1900 is 18.9. I can write therefore −2.6 for 1891, −2.2 for 1892, &c. These figures of deficit or surplus of bushels per acre can be used to draw maps.*

The figures utilized to establish the annual departures for the different States of the Union are those given by Charles C. Clark.† The figures for the provinces of Ontario and Manitoba are taken from Canadian official publications.‡ As the departures are written on the following maps (figs. 2–11) it is unnecessary to reproduce them in tabular form.§

To simplify the examination and comparison of the maps I have drawn curves of equal departures. In this way the areas of deficit and surplus can easily be distinguished.

From the examination of these maps it may be inferred that the two first hypotheses expressed on the subject of compensations are correct. For, looking at the geographical distribution of the departures, one must acknowledge that centers of exceptionally good or bad harvests really exist, that the extent of these areas is generally much smaller than the extent of the United States, and also, that the points where the most favorable or the most unfavorable conditions are centered, displace themselves, and that, in reality, we have to do with a phenomenon of a dynamical order.

The maps of the years 1893 and 1898 should be examined to begin with.

The wheat crop was bad almost all over the United States in 1893, while in 1898, on the contrary, the harvests were above the average, one may say, everywhere. But, in both cases, the values of the figures are disposed in such a fashion that we are bound to admit that the factors upon which the crops depend proceed by waves. In 1893 the figures — 7.3, — 7.2, — 7.6 for the States of Nevada, Utah and Colorado occur along a line at the end of which we observe the departure — 4.3 in Kansas, and farther on, — 1.2 and — 1.3 in the States of Arkansas and Mississippi. Beside this negative wave, there is one of positive values extending from North Carolina to Indiana, and on the prolongation of this wave we note,

* The average yield being quite different from one region to another (the extreme means for the ten years 1891 to 1900 are 7.2 for South Carolina and 25.2 for Montana), it would be well to correct the departures by calculating them in per cent. of the average yield. I used the uncorrected departures in making my maps.

† Wheat crops of the United States, 1866–1906. (U. S. Dept. of Agriculture, Bureau of Statistics —*Bull.* 57, Revised.)

‡ Nineteenth Annual Report of Ontario Bureau of Industries, p. 25.
Statistical Year-Book of Canada, 1900, p. 79.

§ The maps show that the departures for Vermont must be considered as being doubtful

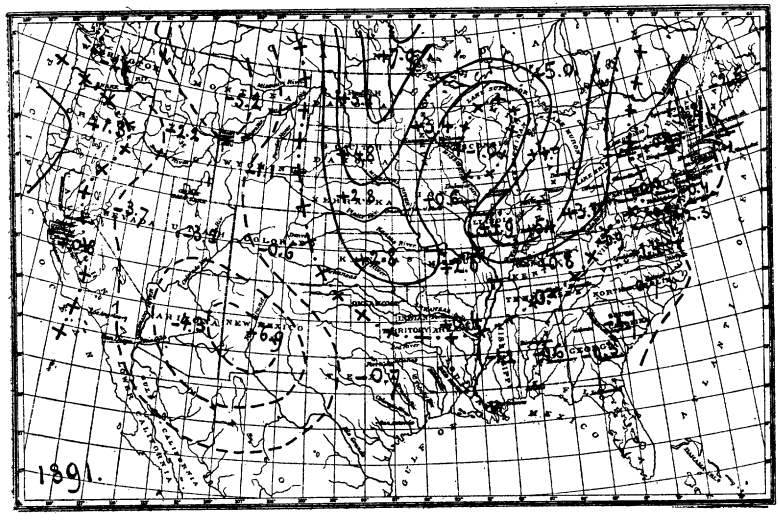
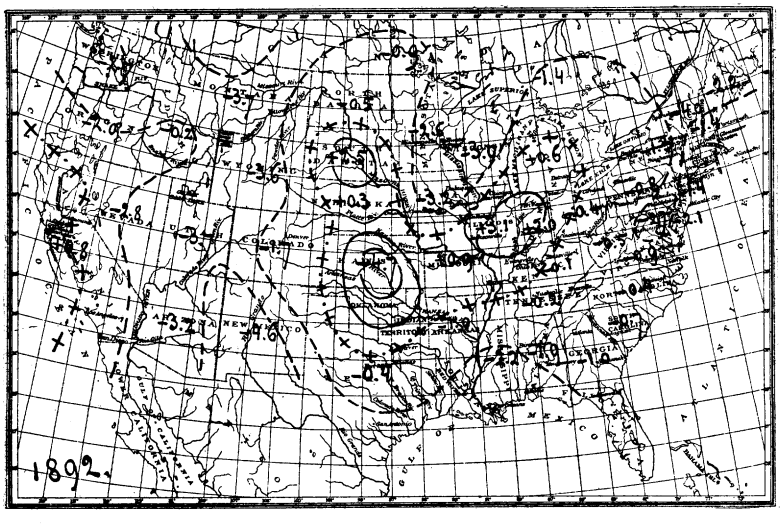


FIG. 2.



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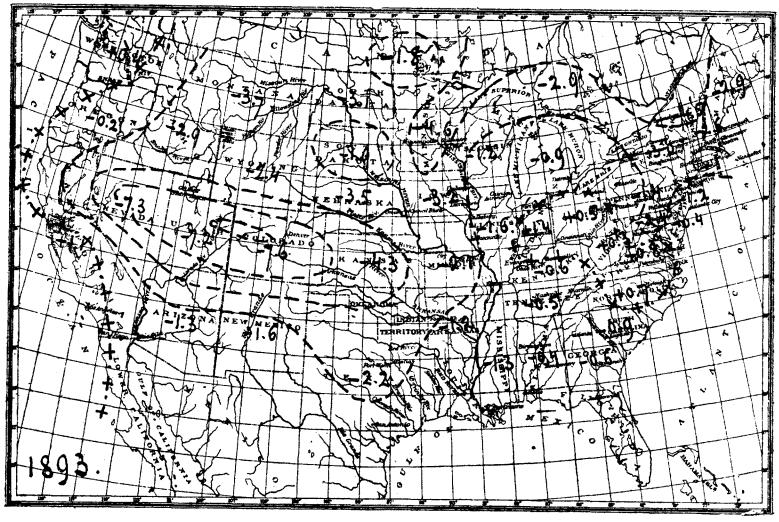

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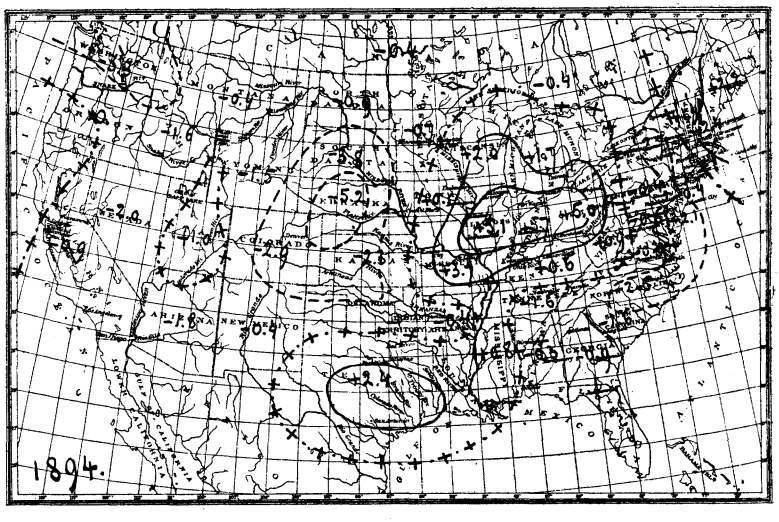

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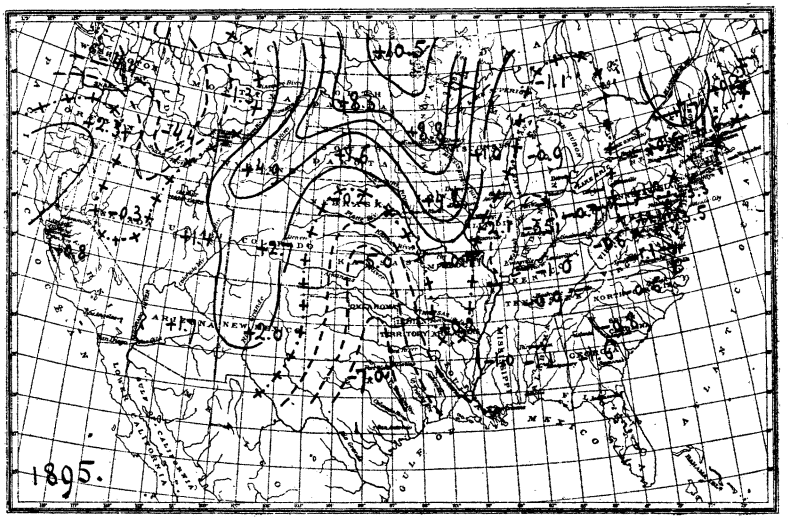

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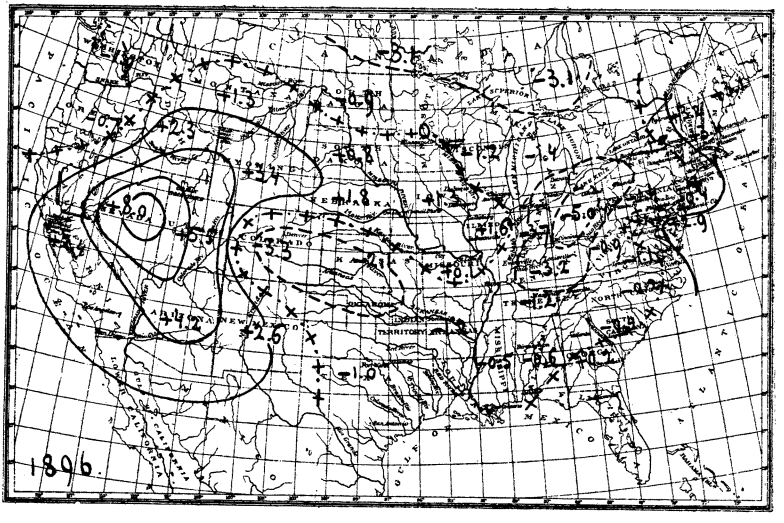

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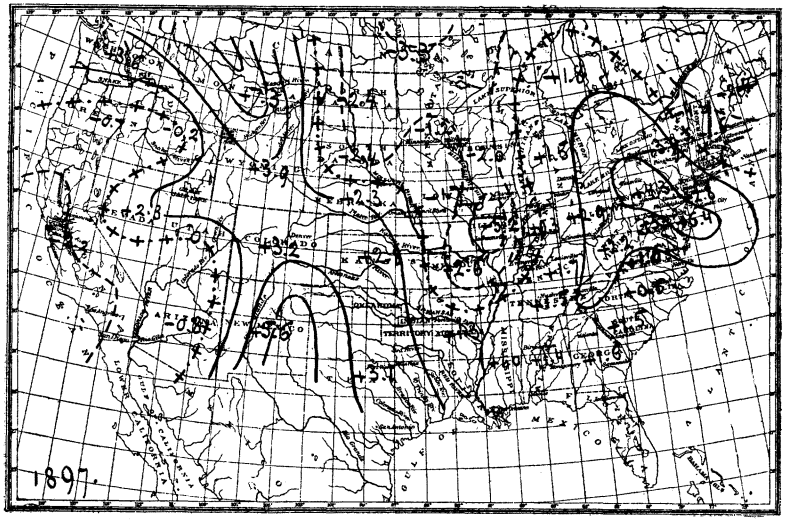

FIG. 8.

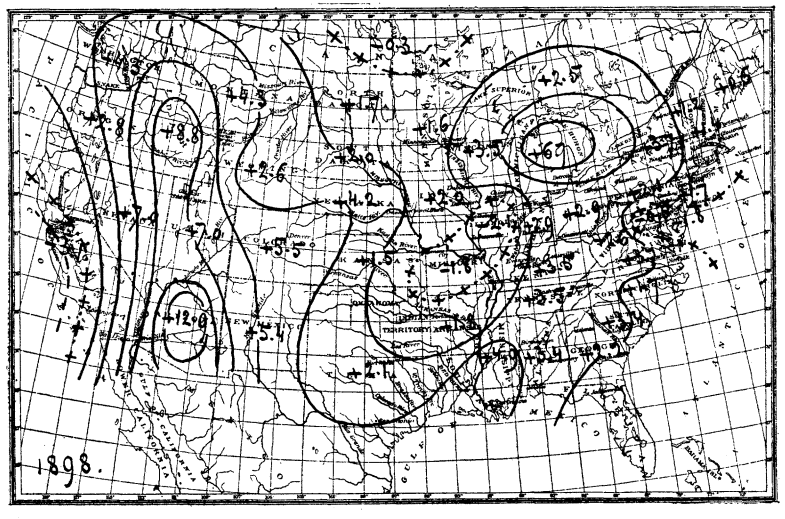

FIG. 9.

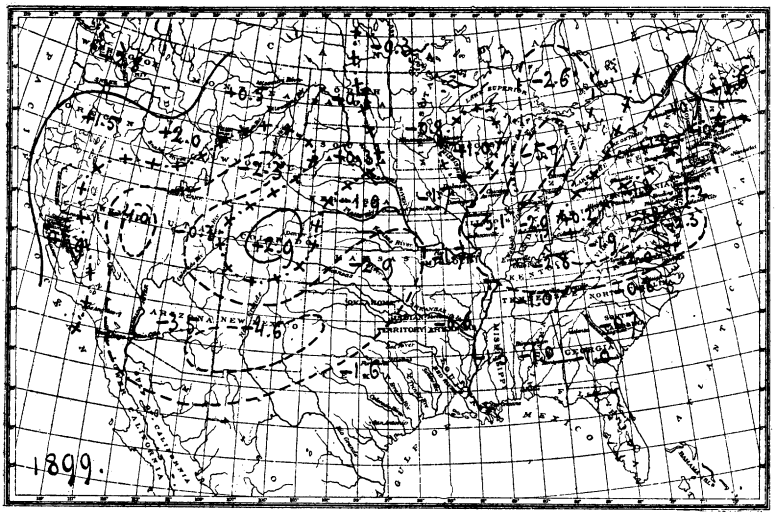

FIG. 10.

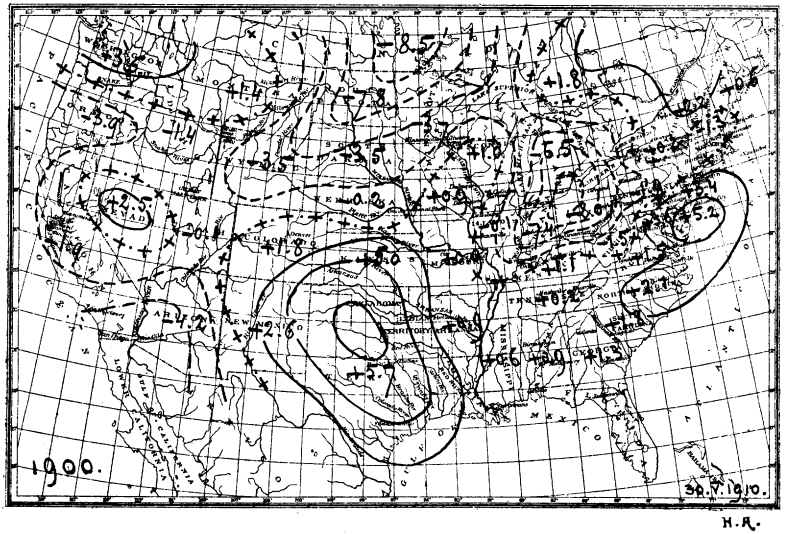

FIG. 11.

in South Dakota, the departure — 1.9, which is less negative than those in the neighboring States.

The map of 1893 is still more curious. The excessive value of +12.9 bushels per acre in Arizona is followed by +7.0 in Utah and Nevada and +8.8 in Idaho; more to the north the crest of this positive wave extends into Canada, since the departures in Montana and Washington State are +4.3. Another positive wave, less distinct, however, extends from the Gulf of Mexico to the Great Lakes, and between these two waves of excessive crops we find values below the average, −0.3 in the Province of Manitoba, and −2.1 and −1.8 in Illinois and Missouri.

It seems to me that these phenomena could not be explained by local causes, independent of the anomalies of meteorological conditions, and that the study of the climatical changes, on the contrary, shall supply a scientific explanation of these facts. Now let us compare the maps of successive years. Those of 1891, 1892 and 1893 show some interesting points of resemblance. The positive area of 1891 extends from Canada to Arkansas. In 1892 this area diminished in extent, and the center of highest positive value moved from Manitoba to Kansas, and instead of +7.9 it is +4.7 that we note. In 1893 there are still positive departures, but only in a small portion of the country, and the highest value (Indiana) is reduced to +1.4.

Thus: a decrease in extent and a displacement in the opposite direction to the hands of a clock. The negative wave stretching, in 1891, from Montana to Mexico, seems to have followed the same movement. A really curious fact to be remarked is, that I noted exactly the same movement on the maps of annual departures of temperature.* I do not insist on this detail as the question of the correlations between crops and the dynamical phenomena of climates must be fully studied, point by point and progressively, step by step. However, two facts are at present sufficiently well established to attract our attention.

First, the areas occupied by positive or negative departures on the maps of annual data of temperature, atmospheric pressure, and yield of wheat are comparable in extent. The same fact is shown in a series of maps I have drawn for the departures of rainfall observed in the United States.† Then, the disposition of the

* Arctowski: L'enchaînement des variations climatiques, p. 105, Brussels, 1909.

† This research will form the subject of a special paper. The utilized data are those published by Frank H. Bigelow (U. S. Dept. of Agriculture, Weather Bureau, Climatological Division, Abstract of data No. 3).

The departures which I have utilized to draw the maps have been calculated in per cent. of the normal values, exactly in the same way as H. R. Mill has done for the rainfall maps of Great Britain and Ireland. (British Rainfall, 1908.)

thermopleions and anti-pleions of my maps of annual temperatures forced me to admit the existence of waves which displace themselves. In my preceding paper* I have shown that for atmospheric pressure the same thing most probably exists. As the maps of wheat crops give similar indications, it is reasonable to admit that the crops depend on the same atmospheric changes as those which cause the appearance and propagation of thermopleions and anti-pleions, as well as hyper- and hypo-pressure areas. I have already insisted upon the waves which appear on the maps of 1893 and 1898. I wish to add some words about those of the other departure-maps of wheat crops which are sufficiently well marked to be worthy of mention.

The positive wave which, in 1894, extends from the Great Lakes to Texas, shows two centers of excessive positivity, very lightly joined. A third nucleus of excessive crop appears on the extension of this wave towards the NE. In Nebraska a departure of -5.2 counterbalances that of $+5.7$ of Indiana.

The map of the following year looks as if there had been a displacement towards the W. with an accentuation of positivity. In this hypothesis the departure $+10.5$, of Manitoba, would be due to the surplus center $+5.7$ observed in Indiana in 1894. The maps of 1897 and 1898 show a case of exactly the same kind and quite as interesting. The positive wave extending from Montana to New Mexico, in 1897, is seen the following year a little farther to the W. At the same time the positive wave of 1897, the crest of which is directed from Lake Huron to Cape May, followed this movement, going to the NW. The transformation of the map of 1899 into that of 1900, if any connection does exist between the two maps, can only be explained, it seems, by a northwesterly displacement. Moreover, if the map of 1899 but slightly suggests the existence of two systems of waves, directed from the NE. to the SW. and from the NW. to the SE., that of 1900 shows these intercrossing waves so clearly, that one must be prejudiced not to admit their existence.

Let us see now how things went on in Russia and Central Europe.

From the data of a paper by I. M. Rubinow† and those collected

* *Bull.* of the Amer. Geogr. Soc., vol. 42, p. 270.

† I. M. Rubinow: Russia's wheat surplus, p. 29, Washington, 1906. (U. S. Dept. of Agric., Bureau of Statistics—*Bull.* No. 42.)

by Frank R. Rutter,* I have formed the means and the departures of the means shown in the following table:

REGIONS.	MEAN.	*1891.*	*92.*	*93.*	*94.*	*95.*	*96.*	*97.*	*98.*	*99.*	*1900.*
	Bush. p. acre:										
Centr. agric. region....	9.0	—5.4	—4.1	+2.5	+2.9	+3.6	—1.2	—3.5	0.	+1.8	+3.1
Middle Volga.....	6.8	—3.8	—0.9	+0.1	+2.7	—0.8	+2.8	—1.3	—1.8	+2.5	+0.9
Lower Volga.....	7.1	—4.7	+2.8	—1.0	+2.9	—0.2	+1.5	—1.8	—1.8	+0.3	+2.2
New Russia.....	7.7	—2.1	—1.5	+5.1	+2.0	+0.6	—0.6	—1.3	+1.8	—1.9	—1.5
Little Russia.....	9.6	—2.4	—2.9	+2.0	+1.8	+1.9	—1.3	—0.8	+2.6	—0.1	—0.4
Southwestern region...	13.1	—3.1	—3.3	—1.4	+3.0	+2.9	+2.1	—4.8	+3.9	+4.5	—4.0
Ural.....	10.3	—6.1	—1.5	—1.6	+1.9	+0.3	+2.9	+0.1	—0.8	+3.2	+2.1
Moscow industr. region.	8.9	+0.5	—1.4	—0.5	+0.7	—0.4	+0.5	+0.5	+0.8	+1.3	—2.8
White Russia.....	10.4	—0.7	+0.5	+0.1	+0.4	—1.5	—0.4	—1.4	+1.9	+1.3	—0.3
Lithuania.....	11.3	—1.5	—0.9	+0.8	—0.3	—1.0	0.	+0.3	+1.9	+1.2	—0.5
Baltic region.....	15.7	—0.8	—5.0	+0.5	+0.6	—3.2	+0.7	+0.5	+2.4	+3.4	+1.3
Sweden	24.8	—0.1	—0.2	—2.5	+0.1	—3.7	+1.9	+1.5	+0.4	—0.4	+3.2
Roumania.....	14.6	—1.9	+2.7	+4.3	—1.9	+4.7	+4.5	—5.4	+1.7	—8.3	—0.2
Germany.....	25.2	—6.8	—1.4	—0.4	—0.2	—0.8	+1.2	+0.1	+2.0	+3.2	+2.7
Hungaria.....	17.9	+0.5	+0.6	+1.6	+0.3	+2.8	+1.5	—6.2	—0.8	—0.1	—0.6

I have put these figures on maps in order to get a clear idea of the geographical distribution of annual surplus or deficit of the crops of wheat. These maps are much less detailed than those of the United States, where 44 departures could be utilized each year. I do not reproduce my drawings because later I hope to obtain the necessary data to make detailed maps, which will in consequence be more accurate. Therefore I shall restrict myself at present to a few statements of a general order.

In Russia, as in the United States, there are no regions which could be considered as being the permanent centers of the observed variations. It is not always the same provinces of the Empire which are the most or the least favored. So it seems that in Europe, as in America, the zones of surplus and deficit displace themselves. However, the variations are more accentuated as the distance from the ocean increases. It is in the south of Russia and toward Asia that the changes of the crops are most pronounced. The greatest difference in the annual yield of wheat per acre, for the ten years taken into consideration, is 6.9 in Sweden, where the average is 24.8. In the lower basin of the Volga (provinces of Samara and Astrakhan), where the annual yield is only 7.1, that is to say less than the third of that of Sweden, the difference between the values of the years 1891 and 1894 reaches 7.6 bushels per acre, a fluctuation which is therefore four times greater than that observed in Sweden. In Rumania also the difference between the greatest departures is 13.0 for an average crop of 14.6.

* Frank R. Rutter: Cereal production of Europe, Washington, 1908. (U. S. Dept. of Agric., Bureau of Statistics—*Bull.* No. 68.)

Let us examine the geographical distribution of the departures for the years 1891, 1893 and 1897, that is to say the years for which the total production of wheat in Russia is most strikingly in contrast to that of the United States.

In 1891 the yield of crops did not surpass the average of the ten years except in the "industrial region" of Moscow (provinces of Tver, Moscow, Kaluga, Yaroslaw, Vladimir, Kostroma). A positive departure was also observed in Hungary, but there, as well as in the region of Moscow, the excess was only + 0.5. In Germany the negative departure was — 6.8, and in the central agricultural region of Russia and in the E. and SE. of the Empire the departures are, all proportions maintained, still more negative. The figure — 0.7, for White Russia, indicates that the two centers of very bad crops in question were separated by a wave of better yield of crops, by a wave directed from the region of Moscow towards Hungary.

The geographical distribution of the departures for 1893 shows the existence of a wave which crosses the Russian Empire in a perpendicular direction to that of the positive wave of 1891, inasmuch as the figures permit a judgment. It is in Rumania and in southern Russia that the most positive departures are observed, and then, it is from the Don and the Volga towards the Baltic Provinces that the wave in question extends, separating the regions characterized by a deficit in crops. On this point it is interesting to notice that the negative wave of 1893, in the United States, followed also an almost perpendicular direction to that of 1891.

In 1897 the boundary line between the positive and negative departures, in Russia, extends from E. to W., from the Ural towards Germany. The crops are a little above the normal value in the N. (in Sweden even + 1.5 per acre), while in the S. they were very bad, especially in the SW., and in Hungary and Rumania, as well as in the central agricultural region (provinces of Riazan, Tula, Orel, Kursk, Voronezh, Tambov) where a second center of deficiency is observed. A comparison with the United States leads to very suggestive conclusions.

As an hypothesis, I may venture to say that on both sides of the Atlantic, across North America and across Europe, and perhaps even Asia, a common factor of dynamical order governs simultaneously all the variations.

Notwithstanding the fact that the maps I have drawn for Russia are much less satisfactory than those for the United States, I cannot refrain from adding to the preceding remarks that, in 1898

1899 and 1900, years during which the curves of fig. 1 are not of an opposite character, the maps show certain analogies which are really striking. In 1898, in Russia, the departures are + 3.9 in the W. and — 1.8 in the E. A great positive wave seems to cross Europe from the N. to the S. The American map shows something similar. In 1899, in Europe as well as in America, the values are negative in the S. and positive in the N. The departures of 1900 observed in Russia suggest an intercrossing of waves quite the same as seems to have been the case in the United States.

From the fact that in Russia and in the United States the variations of the figures of wheat crops, for the years 1897 to 1900, are similar, I have deduced the conclusion that, for the needs of the international market, there may be exceptional years of insufficient compensations.

To be convinced of this it is sufficient to examine the price of wheat in England.*

In 1891–92 the price of grain was 101.6 cents a bushel; then the price diminished till 1894–95, when it was as low as 64.8; rose again to 110.3 in 1897–98, then gradually went down to about 80 cents.

GRAIN CROPS AND POTATOES IN THE UNITED STATES, 1891-1900 (IN MILLION BUSHELS).

PRODUCTION OF	*1891*	*92*	*93*	*94*	*95*	*96*	*97*	*98*	*99*	*1900*
Corn.....	2,060	1,628	1,619	1,212	2,151	2,283	1,902	1,924	2,078	2,105
Oats.....	738	661	638	662	824	707	698	730	796	809
Wheat....	611	515	396	460	467	427	530	675	547	522
Potatoes..	254	156	183	170	297	252	164	192	228	210
Barley....	86	80	69	61	87	69	66	55	73	58
Rye.....	31	27	26	26	27	24	27	25	23	23
Buckwheat	12	12	2	12	15	14	14	11	11	9
Total...	3,792	3,089	2,933	2,603	3,868	3,776	3,401	3,612	3,756	3,736

Following another idea, the above table gives in millions of bushels the production of corn, oats, wheat, potatoes, barley, rye and buckwheat, for the years 1891 to 1900, in the United States.†

By adding the figures we see that the agricultural production diminished during the years 1891 to 1894 from 3,792,000,000 of bushels to 2,603,000,000, making a deficit of 1,189,000,000 bushels,

* Rubinow: loc. cit., *Bull.* 66, p. 77.

† U. S. Dept. of Agric. Bureau of Statistics—Bulletins: 56, 57, 58, 59, 60, 61 and 62.

which is almost a third, or perhaps more, if the figures were divided by the numbers of inhabitants forming the population of these years.*

It seems to me unnecessary to dwell on the signification of the preceding figures from the commercial point of view. On the other hand, I cannot let pass without comment certain apparent contradictions. The variation of the production of wheat, for example, is notably different from that of potatoes. It is easily understood that certain meteorological conditions favorable to wheat might be unfavorable to the development of potatoes. The same thing is true of corn. R. H. Hooker has made a detailed statistical study of the meteorological conditions favorable or unfavorable to the different crops in England.†

He has found that in England, of course, "the absence of rain in September and October is more important to the wheat crop than rain or temperature at any other period of the year." Another interesting result of Hooker's work is that "the advantage of cool weather during spring and summer for the great majority of the crops" . . . is a "feature [which] stands out with quite unexpected prominence."

It is probable that in other climates conditions are not the same, and it is clear that the influence of each meteorological factor should be studied, region by region and separably, for each particular cereal. The difficulties in the way of foreseeing the yield of crops are enormous. However, this problem can be attacked and its solution is attainable.

I think I have shown that the maps giving the annual distribution of wheat crops are of such a character that, in order to explain them, it is necessary to have recourse to meteorological influences depending on the general circulation of the earth's atmosphere.

The amount of meteorological observations which has been accumulated in the course of years is enormous, and it is perfectly possible, at present, to study scientifically the simpler problems of the climatical changes. I really believe that even if the true connections between the causes and the effects escape us, yet practical results will be obtained by applying purely empirical methods.

* The increase of the population from 1891 to 1894 was about 3,788,000 (Statistical Abstract of the United States. 1908).

† R. H. Hooker: Correlations of the weather and crops. (Journ. Roy. Statistical Soc., vol. 70, p. 1. London, 1907.)